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This is to certify that the thesis prepared by Rhonda S. Houser entitled 'The Use of Geographic Information Systems to Model Habitat for *Puma concolor cougar* in the Northern Blue Ridge of Virginia' has been approved by her committee as satisfactory completion of the thesis requirement for the degree of Master of Interdisciplinary Studies.

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The Use of Geographic Information Systems to Model Habitat for *Puma concolor cougar* in the Northern Blue Ridge of Virginia

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Interdisciplinary Studies at Virginia Commonwealth University.

by

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Abstract

Geographic Information Systems (GIS) was used to predict suitable habitat for the eastern cougar (*Puma concolor cougar*) in the Northern Blue Ridge of Virginia. Two areas were studied, a primary area nested inside a secondary area. Objectives were accomplished by relating eastern cougar sighting locations, the dependent variable, to environmental variables considered important to habitat. These variables were elevation, geology, human density, land cover, landform, prey density, roads, and streams/rivers. Logistic regression identified elevation, geology, landform, and distance to the nearest road as significant predictor variables for the primary area, and no variables for the secondary area. The significant variables were fit to the regression equation, resulting in a sighting probability coverage, from which suitable habitat areas were derived and suitability was tested with additional sighting data. The regression equation generated by primary area data was applied to the secondary area and two habitat models were built, one with and one without the roads variable. Chi-square results indicated that three of the five habitat models tested were significantly better than random. The efficacy of predicting habitat suitability based on eastern cougar sighting data was dependent on the scale and quality of these data.

Key words: carnivore, conservation, cougar sightings, eastern cougar, *Felis concolor cougar*, GIS, Geographic Information Systems, habitat model, habitat suitability, logistic regression, *Puma concolor cougar*, species sighting data, wildlife habitat

Introduction

The eastern cougar, *Puma concolor cougar*, has also been called the American lion, catamount, mountain lion, painter, panther, and puma, and was once the most ubiquitous mammal in the Western Hemisphere. The range of the eastern cougar included southern Canada and the eastern United States, from Nova Scotia, New Brunswick, southern Ontario, and lower Michigan to Indiana and Kentucky on the west, and Tennessee and South Carolina in the south (Figure 1; Handley 1979). Hunting, trapping, habitat loss, and decreases in prey populations were threats to the eastern cougar (Downing 1984). Extreme decimation of white-tailed deer populations toward the end of the nineteenth century may have contributed greatly to a decrease in eastern cougar numbers (Wright 1972). In addition, the eastern cougar was considered a pest during this time and sizeable bounties were offered for its killing (Greenwell 1994). Historical distribution of the eastern cougar in Virginia is thought to have been statewide, with populations persisting in the mountain counties of western Virginia until the late nineteenth century (Wright 1972). The last eastern cougar native to Virginia was killed in Washington County in 1882, and the eastern cougar was virtually absent throughout its range around the end of the nineteenth century (Bolgiano 1995).

Sightings of eastern cougars in Virginia decreased greatly after the 1880s, and remained at a minimal level for the next 50 to 75 years (Bolgiano 1995). Deer populations also dwindled during this period, during which forested areas were often destroyed or greatly altered by frequent and uninhibited burning (Handley 1979). Remnant deer populations persisted and began to flourish again in the 1930s and 1940s, aided by the passage of the 1914 Weeks Act, which protected areas of deer habitat within National Forests (Greenwell 1994). White-tailed deer were protected and restocked during the 1930s, resulting in an increase and expansion in the deer population, and a subsequent rise in the number of eastern cougar sightings by the 1960s (Bolgiano 1995, Downing 1981). The current regulatory status of the eastern cougar is *Endangered* at the federal level and considered to be extirpated in the wild in Virginia (USFWS 1991). The Florida subspecies of cougar, Florida panther (*Puma concolor coryi*), is also *Endangered* throughout its entire range, threatened predominantly by habitat loss as a result of agricultural activities, urban sprawl, and road-related mortality (Downing 1990). The western cougar, *Puma concolor*, is currently not federally listed and is subsisting well, with many western states supporting healthy populations (Shaw 1996).

Puma concolor, the parent species of the eastern cougar, is the most widespread mammal in the New World, and has thus adapted to a variety of habitats (Greenwell 1994). Young and Goldman (1946) identified 30 subspecies, Greenwell (1994) recognized 27, and Gay and Best (1996) stated that more than 25 subspecies occur. Currently, *Puma concolor* is taxonomically classified into 32 subspecies (Culver et al. 2000). The effort to classify *Puma concolor* on a sub-specific level is exacerbated by the difficulty of detecting morphological differences between specimens from the southern and western parts of the eastern cougar's range and specimens from the northern and eastern parts of the range. In addition, the potential for hybridization exists where the ranges of subspecies overlap (Downing 1981). However, Handley (1981) noted that the designation of many subspecies, especially those from South America, was based on too few specimens and/or insufficient differentiation, and that reclassification would most likely result in fewer than 27 subspecies. A recent genomic study recommended six phylogeographic groupings of *Puma concolor* subspecies (Culver et al. 2000).

The adult eastern cougar has a dorsal pelage ranging from tawny or another shade of brown in the summer, to a grayish tint in the winter (Burt and Grossenheider 1976). It is the largest obligate carnivore in the eastern United States, with the average adult male ranging from 2.1 to 2.7 m in length, weighing from 70 to 90 kg, and having a tail measuring from 0.68 to 1 m in length (Burt and Grossenheider 1976). The eastern cougar is solitary and primarily nocturnal, but may also hunt and travel during the daytime, especially during late afternoon (Burt and Grossenheider 1976). White-tailed deer, *Odocoileus virginianus,* are the main prey for the eastern cougar, while other ungulates and small mammals may supplement the diet (Burt and Grossenheider 1976). The eastern cougar does not exhibit pack behavior, and the average home range was estimated at 25 to 50 sq. km (Guggisberg, C. A. W. 1975). Optimal eastern cougar habitat in Virginia was described by Handley (1979) as "extensive mountain hardwood forest, or mixed forest with rocky outcrops and ledges, and thickets of mountain laurel, rhododendron, and greenbrier." The eastern cougar utilizes dens only on a temporary basis except during breeding season, and makes use of various shelters provided by caves, fallen trees, fissures in cliffs and ledges, isolated areas of dense vegetation, and overhanging rocks (Burt and Grossenheider 1976).

The eastern cougar was identified as an umbrella species, or one that "requires large blocks of relatively natural or unaltered habitat to maintain viable populations" (Meffe et al. 1997). Conserving the substantial amount of habitat necessary for the home range of such an umbrella species, would theoretically result in protection of many other species utilizing the same habitat and resources (Noss et al 1996). The eastern cougar may also act as a pivotal species, whose population status provides a general representation of the overall health of the ecosystem which it and other species inhabit (Noss et al. 1996). Conservation planning may benefit from using carnivores such as the eastern cougar as representative species, since relatively more biological information is available for carnivores (Noss et al. 1996). In addition, carnivores often have a large impact on community structure, are appealing and successful symbol for conservation in the public eye, and can be more efficiently monitored than an entire ecosystem (Noss et al. 1996).

Various factors influence the type of habitat used by large predators such as the eastern cougar, and relative population abundance of mammalian carnivores are affected by the ecological components of a given geographic area (Smallwood and Schonewald 1996). A Geographic Information System (GIS) is defined as "a unique system designed for a particular application that stores, enhances, combines, and analyzes layers of geographic data to produce interpretable information" (ERDAS 1999). The power of GIS lies in the capability of the system to create new layers of spatial data by combining data from two or more existing data layers (Lyon and McCarthy 1995). GIS is appropriate for this analysis, as it allows for application of a quantitative tool to ecological factors, and also facilitates multiple comparisons and analyses of these variables when they are manipulated as spatial data layers.

GIS was used to examine the hypothesis that suitable habitat for the eastern cougar is present in the Northern Blue Ridge area of Virginia. In addition, the hypothesis states that deer harvest density, elevation, geology, human population density, land cover, landform, roads, and streams/rivers are important variables in defining suitable habitat. Wildlife habitat quality was defined by the capacity of a land area to provide the resources and conditions necessary for occupancy by more or less individuals (Ortega-Huerta and Medley 1999). The objectives of this study were: 1) to collect reliable and detailed eastern cougar sighting data; 2) to collect data for environmental variables presumed to be important in defining suitable habitat for the eastern cougar; 3) to examine the relationship between the locations of cougar sightings and the environmental variables identified as important to cougar habitat; and 4) to predict areas of suitable habitat in the Northern Blue Ridge study area based on where eastern cougar sightings occurred in relation to the environmental variables.

Methods

This study involved two land areas, a primary area defined by ecological boundaries nested inside a secondary area defined by political boundaries. Designation of two study areas was primarily for practical reasons as deer harvest data are available only on a county-by-county basis. Also, eastern cougar sighting data were obtained for an area inside the primary study area and also for the entire study area, necessitating the differentiation of land areas based on the availability and quality of these sighting data. The following variables were identified as important in defining suitable habitat for the eastern cougar and used in building the spatial habitat model: antlered male deer harvest density, human population density, elevation, geology, landform, land cover, distance to nearest road, and distance to nearest stream/river.

The variable deer harvest density as a population indicator was chosen, as white-tailed deer are the main prey of the eastern cougar, and deer density may affect eastern cougar density (Burt and Grossenheider 1976, Handley 1979). Human population density and roads were chosen, as these factors may be negatively correlated with eastern cougar numbers (Maehr 1997, Maehr and Cox 1995). Elevation, geology, landform, land cover, and streams/rivers were chosen as variables that may help define optimal eastern cougar habitat (Burt and Grossenheider 1976, Riley and Malecki 2001, Smallwood and Fitzhugh 1995).

Study Area Descriptions

The primary study area boundary was the Northern Blue Ridge area of Virginia, identified by the U.S. Forest Service as the Northern Blue Ridge Mountains Subsection (Figure 2; Keys et al. 1995). This area is easily distinguished as an ecological and geographical unit, based on various biological and physical factors, including climate, landform, geomorphology, geology, soils, hydrology, and potential vegetation (Keys et al. 1995). The Northern Blue Ridge Mountains Subsection is part of the Blue Ridge, a discrete mountain chain that extends northward from the Roanoke River Gap in southern Virginia into southern Maryland and Pennsylvania (Keys et al. 1995). The primary study area includes only the portion of the range that lies within Virginia, encompassing a land area of approximately 6,120 km^2. This area contains one mountain range that is nineteen to 23 km wide, and Shenandoah National Park is topographically characteristic of the Subsection with elevation values ranging from 275 to 1237 meters (Braun 1950). The primary area follows the crest of the Blue Ridge Mountains and includes portions of the following counties: Albemarle, Amherst, Augusta, Bedford, Botetourt, Clarke, Fauquier, Greene, Loudoun, Madison, Nelson, Page, Rappahannock, Roanoke, Rockingham, Rockbridge, and Warren.

The secondary study area was the Blue Ridge Mountains Section, which encompasses the Northern Blue Ridge Mountains Subsection and adjoining counties, and covers approximately 21,800 km^2 (Figure 2). Average precipitation for the area ranges from 1,020 to 1,270 mm, but may reach 1,500 mm at the highest elevations, and average annual temperature is 10 to 16 ºC (Keys et al. 1995). Oak-chestnut communities were ubiquitous throughout this area prior to the arrival of chestnut blight, an introduced pathogen that caused extensive damage to forest stands by top-killing all American chestnut trees from 1920 to 1940 (Keys et al. 1995). Currently, forested vegetation of this area is characterized by mixed-oak forest, but also contains inclusions of environmentally restricted, small-patch vegetation types (Stephenson et al. 1993).

Spatial Data Collection and Processing

All spatial data were projected using the Universal Transverse Mercator projection, Zone 17 (UTM 17), North American Datum 1983 (NAD 83). A projection should result in minimal distortion of the geographic features most important to an area or study, as various combinations of area, direction, distance, and shape may be misrepresented by a given projection (ERDAS 1999). The UTM projection is appropriate for land areas oriented north to south and occupying one geographic zone, as is the case for the primary study area and the majority of the secondary area (ESRI 1999). ArcView was used for generation and processing of all spatial data, unless otherwise noted. Data were reprojected into the UTM 17, NAD 83 projection using the ArcInfo PROJECT command and clipped to the secondary study area boundary, unless otherwise noted. In coverages having a resolution of 30 m, each cell in the image or grid represents a 30 by 30 m area on the ground. Various organizations and state and federal agencies were the sources of spatial data for the eight environmental variables (Table 1). Spatial data for the primary study area was based on ecological units, as described above. This coverage was reprojected, converted to a shapefile, and clipped to include only the land area within

Virginia. Spatial data for the secondary study area boundary were generated using a county coverage, which was converted to a shapefile and edited to retain the seventeen counties that comprised the secondary area.

The eastern cougar sighting data were digitized into a GIS as point features. The SNP data consisted of a Microsoft Access database, from which 84 sightings occurring from 1990 to 1998 were extracted. The majority of these sightings were located inside the Park, and all occurred within the primary study area boundary. Physical sightings, sign (scat, carcass, other), and tracks were included and are referred to henceforward as sightings. Additional criteria included sightings for which the observer held a medium to strong conviction that the animal seen was a cougar, and those that contained sufficient location information to be digitized in the GIS. These tabular sighting data were converted to spatial format using roads, topographic maps, and geographic place names as reference coverages (Figure 3). Using similar procedures, a coverage of 45 sightings was generated from the SNP database to use in testing the prediction ability of the final habitat model (Figure 3). This coverage contained different sighting locations than those to be used in building the model. The second sighting data set from the EPRN consisted of a map of 59 sightings occurring from approximately 1983 to 1999, within the secondary study area boundary (Figure 3). The two data sets may have contained some of the same sightings but this was impossible to discern due to the lack of detail available in the second data set.

The sighting point coverages were converted to 30-meter grids and buffered with a radius of 125 meters using the Neighborhood Statistics tool, such that each buffered sighting location covered 0.05 km^2. Buffers were applied to account for sighting biases due to uncertainty of point location and to minimize correlation of sighting locations with easily accessible areas such as roads and scenic overlooks. Similar buffers were applied to cheetah sighting locations in a previous study (Gros and Rejmanek 1999). This is especially relevant to the SNP sighting data, many of which were reported in terms of the nearest milepost, and which may exhibit linear correlation with Skyline Drive. Neighborhood analysis, or rectangular polygon analyses, around plotted sighting locations filters local variability and decreases inherent biases in the data layer, due to point accuracy (Agee et al. 1989, Goodchild 1994, 1996).

Deer population density was estimated using the number of antlered males harvested per county on a yearly basis and averaged per county over the five-year period that the data represented. Antlered male harvest data for white-tailed deer are an appropriate index to use for estimating deer population density, as comprehensive population data are not available (VDGIF 1999). The VARCOMP procedure was used in SAS to estimate the variance components in a general linear model of the deer harvest data. The resulting intraclass correlation coefficient of 0.97 indicated that harvest values varied more between counties than within counties, suggesting further that the harvest values for each county did not fluctuate significantly over five years. Spatial data were generated from tabular data of antlered male harvest numbers, using the counties shapefile, then converted to a 30-meter grid that represented deer harvest density by county (Figure 4).

Elevation data for Virginia were obtained in the form of a 30-meter grid, which was reprojected and clipped in ArcInfo (Figure 5). Virginia geologic data were clipped to the secondary study area boundary, and reclassified such that geology types were represented by the appropriate class (Rader and Evans 1993). This shapefile, comprised of Acidic Granitic, Acidic Sedimentary, Alkaline Sedimentary, Basic Granitic, Mafic, and Mixed/Others classes, was converted to a 30-meter grid. After merging the first two classes to simplify analysis, and merging the Alkaline Sedimentary and Mafic classes based on odds-ratio estimates, the final geology grid for the primary area contained Acidic Granitic/ Sedimentary, Alkaline Sedimentary/ Mafic, and Basic Granitic classes. The secondary area contained an additional Mixed/Others class (Figure 6). Human population data for Virginia for the year 2000 were based on tract boundaries (ESRI 2001). These data were merged, clipped, built into a shapefile, and converted to a coverage in the ArcToolbox module of ArcGIS. The coverage was reprojected in ArcInfo, topology built in ArcToolbox, and then the coverage was converted to a 30-meter grid using the POLYGRID command in ArcInfo (Figure 7).

Land cover data were derived from three georectified Landsat 7(satellite) Thematic Mapper (TM) images taken in February and March of 2000, with 30-meter resolution. Different types of surface features, such as water, soil or vegetation, have different digital number combinations, or signatures, due to specific reflectance and emittance characteristics (Lillesand and Kiefer 1994). The image contained seven bands of data; each band, or raster layer, contains data file values for a particular portion of the electromagnetic spectrum (NASA 2001). The three images were mosaiced, or joined, in Imagine, with Compute Active Area enabled, Overlap Areas as the Matching Method, and the Average Overlap Function as the Intersection option. The image was converted into six grids using the IMAGEGRID command in ArcInfo. Each grid was reprojected and clipped to the study area, using the ArcInfo PROJECT and GRIDCLIP commands, then combined back into a single image using the Layer Stack Utility in Imagine.

Training areas covering the expected diversity within classes were identified by how they displayed using a false color composite, or a 4-3-2 band combination, with near infrared mapped to the red band, red mapped to the green band, and green mapped to the blue band (Lillesand and Kiefer 1994). The classes chosen and how they appeared were: cultivated fields (agriculture) as a pink to light red color, uncultivated (bare) soil as white, coniferous vegetation as rusty red, deciduous vegetation as light green to green, rock outcrops as white to gray, urban areas as light blue/cyan, and water as deep blue (Lillesand and Kiefer 1994). In a previous study, Landsat TM Imagery was classified using similar methods to distinguish between various types of land cover. (Ortega-Huerta and Medley 1999). At least three representative polygons were delineated for each class, resulting in statistics describing the spectral response pattern for each land cover category (Lillesand and Kiefer 1994). The Transformed Divergence method was used to evaluate separability, or differences in polygon signatures within and between classes (ERDAS 1999). The average separability score for this classification scheme was 1946, with a score of 1900 to 2000 being optimal (ERDAS 1999). The image was classified using the Supervised Classification method, with Minimum Distance as the Parametric Rule and all other defaults. Each pixel in the image was compared to the training polygons, and assigned to the category to which it was most numerically similar (Lillesand and Kiefer 1994).

Class accuracy was evaluated by generation of an error matrix, which compared classified data to reference data (Table 2; Lillesand and Kiefer 1994). The Accuracy Assessment was performed in Imagine by overlaying the classified land cover image with a vector coverage of the reference points. The reference data consisted of approximately 500 vegetation plots, primarily 400 m^2 areas, that included comprehensive vegetation and environmental data collected by Division of Natural Heritage ecologists from 1991 to 2000. Overall classification accuracy was 47%. The classified land cover image was exported from Imagine as a grid, and reclassified such that the Agriculture, Bare Soil, Urban, and Water classes were combined into a Non-forested class, the Coniferous and Deciduous classes were combined into a Forested class, and the Rock Outcrop class was unchanged. A Majority Filter was applied five times, which assigned each cell a new value based on the most common value of the nearest eight cells (ESRI 1998). This process smoothes the grid, may reduce classification error, and the resulting file is a more manageable size for analysis (ESRI 1998).

The rock outcrop class was reclassified using Digital Ortho-photo Quarterquads (DOQQs) obtained from Radford University (Radford University 2001). Rock outcrops were identified and digitized as polygons, using DOQQs and USGS paper topographic maps. The accuracy of the merged land cover grid, integrated with the rock outcrop features, was assessed using the vegetation plot data referenced above and the Gap Land Cover Classification as reference data, using similar methods as those used for the initial accuracy assessment (Figure 8; Conservation Management Institute 1999). The overall accuracy was 85% and the overall Kappa statistic was 0.747, suggesting that merging land cover classes and integrating rock outcrop features into the classification, greatly improved classification accuracy for the non-forested and forested classes, in addition to the rock outcrop class.

Generation of landform data was based on work by the Nature Conservancy, with some methods modified, including changing the range of the upper elevation class, adding aspect classes, merging similar landform classes, and building the model from a 30-meter instead of a 90-meter elevation grid (TNC 1999). Land position was first determined for each cell, which included accounting for the mean elevation surrounding each grid cell at varying distances from the center cell (TNC 1999). Slope was derived from the elevation grid using the Derive Slope tool, and the resulting grid was added to the land position grid, generating a landform grid with nine classes (TNC 1999). Aspect was derived from the elevation grid using the Derive Aspect tool, and added to the landform grid with the Map Calculator so that aspect was included in the Cliff, Steep Slope, Side Slope, and Cove classes. After merging classes to simplify analysis and further merging classes per odds-ratio estimates, the resulting landform grid included Cliffs, Low Slopes/Coves, Flats, NE/SW-facing Side Slopes, and Upper Slopes (Figure 9).

The road coverage was reprojected, and edited to retain major roads, including highways, interstates, and primary hard surface roads (VDOT 1999). The streams/rivers coverage was clipped and edited to include only streams or rivers with an order of four to seven. The Find Distance function was used to convert the roads and streams/rivers coverages to 30-meter grids in which each cell value represented the distance from that area to the nearest road or stream (Figures 10 and 11). The resulting floating-point grids, having decimal values assigned to each cell, were then converted to integer grids using the INT command in ArcInfo to compress file size.

<u>Spatial and Statistical Analysis</u>

Random point locations were generated within the primary and secondary study area boundaries using the extension Random Point Generator Version 1.1 (Figure 12; ESRI 2001). The number of points generated within each boundary was equivalent to the number of eastern cougar sightings collected for that area. In previous studies, the number of random locations chosen was equivalent to or greater than the number of sightings (Agee 1989, Gros and Rejmanek 1999, Maehr and Cox 1995). The random location point coverages were converted to 30-meter grids and then buffered with a radius of 125 meters using the Neighborhood Statistics tool, such that each buffered sighting location covered the same land area as did the sighting locations.

Two analyses were conducted as sighting data covered different temporal and spatial ranges. The first analysis was performed in the primary area with the SNP sighting data, and the second analysis was performed in the secondary area with the EPRN sighting data. The Summarize Zones tool was used to determine where each sighting and non-sighting location occurred in relation to the predictor variables. This tool provided values, for each sighting and non-sighting location, that represented where the sighting occurred in each of the predictor data layers. The Summarize Zones analysis calculated a Majority value based on the most common class within each buffered sighting location. The Summarize Zones analysis also calculated a Mean value based on the average of all data values occurring within each buffered sighting location. Majority values computed were used for the categorical variables vegetation and land cover, while mean values computed were used for the continuous variables represented by stream attributes and topography in a similar analysis of jaguar habitat (Ortega-Huerta and Medley 1999).

SAS Version 8.0 was used to perform logistic regression on the sighting and non-sighting locations and predictor variables for each of the two data sets. Logistic regression is often used to examine the relationship between discrete (dependent) responses and a set of explanatory (independent) variables (SAS 2001). Variables that most accurately defined the differences between the random locations and sighting locations were examined using stepwise regression in a previous study (Gros and Rejmanek 1999, Maehr and Cox 1995). Stepwise regression was used and independent variables with a p-value of less than 0.5 were entered into the model and significant variables ($p < 0.05$) were retained in the model for the primary boundary data. Variables with a p-value of less than 0.5 were entered into the model and kept in at a p-value of 0.10 for the secondary boundary data. The intercept and coefficient estimates, from logistic regression for the significant primary boundary variables, were entered into a logit transformation equation (Freund and Wilson 1997). Indicator variables were included for the categorical variables, so that the coefficients applied to the spatial data by the equation varied according to which class value occurred in each grid cell. The logit equation was applied to spatial data for three significant variables in the primary and secondary areas. The equation was also applied to spatial data for four significant variables in the secondary area, resulting in three sighting probability grids.

The probability grids generated by the regression equation were reclassified such that all cells with a 0.00 to 0.50 sighting probability were assigned a relative habitat suitability value of low, areas with probabilities of 0.51 to 0.70 were designated medium, and areas with probabilities of 0.71 to 1.00 were designated high. In a previous study, records of eastern cougar sightings as a measure of sighting potential, were used as an indicator of suitable habitat (Rabinowitz and Nottingham 1986, Smith et al. 1997). In another study, areas were assigned a probability value based on association with sighting locations, and the resulting probability map was used to represent relative areas of habitat suitability (Maehr and Cox 1995).

The final probability grid for the primary area was overlaid with the buffered test sightings and the Summarize Zones tool was used to determine sighting probability values for each of the 45 sighting locations. The final probability grids for the secondary area were overlaid with the 45 SNP test sightings, and also with a combined test data set comprised of the 45 SNP sightings and the 59 EPRN sightings. The Summarize Zones tool was used to determine sighting probability values for each of the test sighting locations. SAS was used to perform a Chi-Square analysis of the test sighting locations in relation to the sighting probability grids. In addition, the final probability grids were overlaid with each of the input environmental variable grids to determine the environmental characteristics at areas considered to be suitable habitat, or those classified as high relative habitat suitability. The Summarize Zones tool was also used for this function.

Results

Majority values, resulting from overlay of environmental variable layers with sighting locations, were used for statistical analyses involving the categorical variables geology, landform, and land cover. Mean values, resulting from overlay of environmental variables with sighting locations, were used for statistical analyses involving the continuous variables deer harvest density, human population density, elevation, distance to nearest road, and distance to nearest stream. The equation resulting from regression analysis predicted the probability of a sighting anywhere within the primary area, as a function of the significant independent variables (Tables 3, 4 and 5). This equation, when extrapolated to the outer study area boundary, also predicted the probability of a sighting anywhere within the secondary area, as a function of the significant independent variables. In the equation, $p = (e^{\hat{y}} / 1 + e^{\hat{y}})$, p is the probability that a sighting would occur in a given area, e is the natural antilog, and $\hat{y}$ is equal to: $\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta 3 x_1 x_2 \ldots$.

The spatial data for three significant variables, elevation, geology, and landform, were fit to the regression equation for the primary area. The spatial data for the significant variables were also fit to the regression equation below for the secondary area, extrapolating the equation to the outer study area boundaries. A second model was generated for the secondary area, with a regression equation that included elevation, geology, landform, and distance to nearest road. The regression equation for the models that did not incorporate the road variable was expressed in the Map Calculator as below:

```
p = (((-2.3472.AsGrid +
    ((0.00785.AsGrid * [Elevation]) +
    (([Geology] = 1) * - 0.3800.AsGrid) + (([Geology] = 2) * 1.0776.AsGrid)) +
    (([Landform] = 1) * - 1.3362.AsGrid)).Exp)/
    (1.AsGrid + ((-2.3472.AsGrid +
    ((0.00785.AsGrid * [Elevation]) +
    (([Geology] = 1) * -0.3800.AsGrid) + (([Geology] = 2) * 1.0776.AsGrid)) +
    (([Landform] = 1) * -1.3362.AsGrid)).Exp)))
```

In this equation, Geology class 1 = Acidic Granitic/ Sedimentary, Geology class 2 = Alkaline Sedimentary/ Mafic, and Landform class 1 = Side Slope NE/SW. These calculations resulted in three 30-meter grids, in which each cell represented a sighting probability value, based on the significant input variables at that location. Each cell represented the probability, from 0 to 1, that a sighting would occur at that location, based on the values of the significant predictor variables.

Regression analysis for the primary area indicated that sightings occurred closer to roads more often, also suggesting that the sightings on which the model was based may have been biased by roads. To avoid incorporating this potential bias into the final habitat model, the roads coefficient was not entered into the regression equation and a roads variable was integrated manually. The distance to the nearest road grid was reclassified so that cells at a distance of 0 to 200 meters from the nearest road were assigned a value of 1, and cells at a distance of 200 meters or greater from the nearest road were assigned a value of 0. The sighting probability grid, resulting from application of the regression equation, was then added to the reclassified roads grid using the Map Calculator. In the resulting habitat suitability grid, values greater than or equal to 1 represented areas that were 0 to 200 meters from a road, and were reclassified as a sighting probability value equivalent to unsuitable habitat. After reclassification, the final probability grids depicted areas of relative habitat suitability (Figures 13, 14, and 15, Tables 6 and 7).

The Chi-square analysis of the primary area model indicated that this habitat model was significantly better than random ($p = 0.025$). Chi-square results also suggested that the two models which were extrapolated to the secondary area, both with and without the roads variable and tested with both sighting data sets, were significantly better than random ($p < 0.001$). In addition, Chi-square tests suggested that the remaining two secondary area models, both with and without the roads variable and tested only with the SNP sighting data, were significantly worse than random ($p < 0.001$, $p = 0.004$, resp.) (Table 8). Stepwise and backward regression for the secondary data set indicated that none of the eight independent variables were significant in predicting sighting locations (Table 3).

Discussion

Spatial and statistical analyses suggested that the first study objective, to collect reliable and detailed eastern cougar sighting data, was accomplished for the primary area although the potential of a road bias should be considered. The second objective, to collect data for environmental variables important to eastern cougar habitat, was met for both study areas. The third and fourth objectives were achieved for the primary area. These were to examine relationships between cougar sighting locations and environmental variables, and to predict suitable habitat in the Northern Blue Ridge based on these relationships. The overall Percent Concordant value of 92.4 indicated that this model predicted where sightings occurred 92.4% of the time; the fit of a model improves as the percent of concordant pairs increases (Freund and Littell 2000). A similar habitat model correctly classified 83% of panther locations, based on sighting locations (Maehr and Cox 1995). The third and fourth objectives were partially met for the secondary area, as relationships between cougar sighting locations and environmental variables were examined by extrapolating the primary area regression equation to the outer boundary.

Results of the primary area analyses suggested that the first hypothesis not be rejected and further indicated that areas of suitable eastern cougar habitat remain in the Northern Blue Ridge. The second hypothesis was not rejected in full as elevation, geology, and landform, three of the initial eight variables, were significant in defining suitable habitat. Spatial and statistical analysis of secondary area data suggested that the hypotheses be neither rejected nor failed to be rejected. It could not be determined whether suitable habitat was present in the larger study area, as no environmental variables were identified as significant to eastern cougar habitat in initial statistical analysis. However, extrapolating the regression equation out to the secondary boundaries allowed some assessment of this hypothesis. Application of the primary area logit equation to the secondary area resulted in two habitat models that were significantly better than random. Thus, even though initial statistical analysis identified no significant environmental variables in the secondary area, extrapolation to the outer boundary was valuable in allowing comparison of habitat models. The secondary model, built with elevation, geology and landform data, contained the highest percentage of relatively high suitable habitat. The secondary model built with roads, in addition to these three variables, contained the second highest percentage of relatively high suitable habitat (Table 6).

The lack of significant variables in initial statistical analysis of the secondary area may be attributed to measurement error. The second sighting data set and subsequent analyses may have included more error as sighting information was rudimentary and coarser than the first data set. The second data set also lacked details such as precise location descriptions, descriptions of what exactly was observed, and information on the reliability of the observer. Also, these sightings included 59 values over a larger land area, while the primary data set contained 84 values over a smaller land area.

Species sighting data are typically not random nor independent; sightings often occur in areas that are most accessible to potential observers such as roads, trails, and so on (Stoms et al. 1993). These spatial and temporal biases may be reduced by buffering sighting locations or using telemetry data when available (Stoms et al. 1993). Sample sizes tend to be too small for robust statistical analysis, which may have affected the lack of significant variables in the second analysis, which involved fewer sightings over a larger area than those examined in the first analysis (Stoms et al. 1993). Sighting locations may include uncertainty and error, which was probably not a factor in the first analysis as these data included detailed descriptions of locations and observations and were filtered to contain only the more reliable sightings (Stoms et al. 1993). Finally, the use of species sighting data to predict habitat may be more appropriate at a coarser resolution to define general habitat preferences, than at a finer resolution to identify specific requirements such as den sites, or daily or seasonal movements (Stoms et al. 1993). Collection or generation of a larger and more comprehensive sighting data set would probably allow examination of relationships between eastern cougar sightings and habitat predictor variables in the secondary area.

Comparing the predictive ability of the environmental variables in this study to other projects may be helpful in explaining the results and in the future design of similar studies. Although deer harvest density was not significant in defining eastern cougar habitat in this analysis, previous studies have shown that frequency and locations of cougar sightings were directly correlated with historical and current distributions and population levels of white-tailed deer (Clark et al. 1985, Culbertson 1977). Inherent biases in antlered male deer harvest data may reduce the accuracy of relative deer population densities. These include differing hunting regulations between and within counties that would potentially affect the number of deer taken, and deer harvesting that is not reported or incorrectly reported to county check stations and/or conducted illegally. Also, deer harvest data were only available at the county level, which was potentially too coarse for this smaller-scale geographic analysis. Although human population data were available on a finer scale than the county level, this variable was also not significant to eastern cougar habitat. This may have been due to the lack of variability in population density in areas where sightings occurred, as much of this area is federally owned and/or rural with relatively low or constant human population density throughout.

Land cover was also not significant in defining habitat, which may be due to various factors. The classification of the Landsat image may have been improved by the availability of a larger and sufficiently detailed reference data set to use both for the selection of training areas and evaluation of classification accuracy. The vegetation plot data used in the accuracy assessment of the final classification, with the outcrop class revised, may have been used by itself for assessing the accuracy of the initial classification if the plots were varied and numerous enough to represent all land cover class types. Ideally, the number of plots for each class would have been proportional to the land area that each class occupied. This may have increased accuracy measurements for the initial classified image, and improved classification of features with similar reflectance values in this imagery, such as bare soil, urban areas and rock outcrops. Land cover was not significant in predicting sighting locations for this model, although a previous study suggested that forested cover was associated with increased cougar presence (Riley and Malecki 2001). In another study, telemetry data indicated a high tolerance for a variety of habitat types but that cover was a critical element of the habitat (Seidensticker et al. 1973). The sighting locations on which the habitat model was based, may be biased by increased occurrence of sightings in open landscapes with a longer range of visibility range (Agee and Sitt 1989). Open areas where eastern cougars were seen may not necessarily be areas of suitable habitat, but areas where eastern cougars were more likely to be observed, regardless of whether the habitat was suitable.

The distance to the nearest stream or river was not significant in this analysis, although hydrological factors were significant variables in previous studies of western mountain lions. For example, western cougar tracks were found along streams more often than expected by chance, were most often detected on roads along first- and second-order streams, and western cougars traveled most frequently along first- and second-order streams that flowed "from mountains or ridges" (Smallwood and Fitzhugh 1995).

Previous studies of cougar habitat suitability found roads to be significant in predicting habitat. Roads may have affected habitat suitability by fragmenting habitat and causing mortality. Males of the Florida subspecies frequently crossed highways, but females appeared to avoid paved roads (Maehr 1997, Maehr and Cox 1995). However, sightings may occur more often on roadsides or in other areas frequented by humans, which may not necessarily be areas of high cougar density. The SNP sighting data set was potentially biased by many sightings occurring along roads and other areas that were easily accessible and highly traveled by humans. Thus, examining the relationship between roads and cougar sightings could be approached using alternative methods. As sighting data may be inherently biased by roads, using the distance to the nearest roadless patch, instead of the distance to the nearest road may better distinguish sighting locations from non-sighting locations. The size and shape of what constitutes a roadless patch would have to be defined, and might include factors such as cougar daily range and tolerance to different road types.

Elevation was the strongest predictor of eastern cougar sighting locations in this analysis, and was also a factor affecting the boundaries of mountain lion home range in a previous study (Seidensticker et al. 1973). Tracks of the western cougar were most frequently detected on mountain slopes, knolls, and peaks, and topographic heterogeneity was associated with increased cougar presence in two studies (Riley and Malecki 2001, Smallwood and Fitzhugh 1995). Another analysis found no correlation between mountain lion sign and elevation in a previous study (Pike et al. 1999). Landscape features important to eastern cougar habitat increased as elevation increased in the primary area. Such features include rock outcrops, continuous forest cover, and landforms less likely to be inhabited by humans (Figures 5, 8 and 9).

In this study, the largest patches of relatively high suitable habitat were located toward the southern end of the primary boundary, extending into Amherst, Augusta, Nelson, and Rockbridge counties (Table 6; Figures 13,14 and 15). A study of Florida panther habitat found that patch sizes greater than approximately five km^2 (500 hectares) had increased likelihood of panther occupancy (Maehr and Cox 1995). Shenandoah National Park also contained several substantial patches, including an elongated patch along the western boundary of Madison county. In addition, the western boundary of Bedford and the eastern boundary of Botetourt exhibited relatively large patches of highly suitable habitat. Further analysis of these data might benefit from consideration of the size, location and connectivity of the moderately and highly suitable habitat areas in relation to eastern cougar home range. These models could also be compared to eastern cougar habitat models generated for the same land area, with particular attention given to the input environmental variables, type of sighting data used, and the resulting areas of suitable habitat. Future research questions might include how to most appropriately incorporate a road variable, the protection status of suitable habitat areas, and whether these areas are threatened by development, especially the construction of roads.

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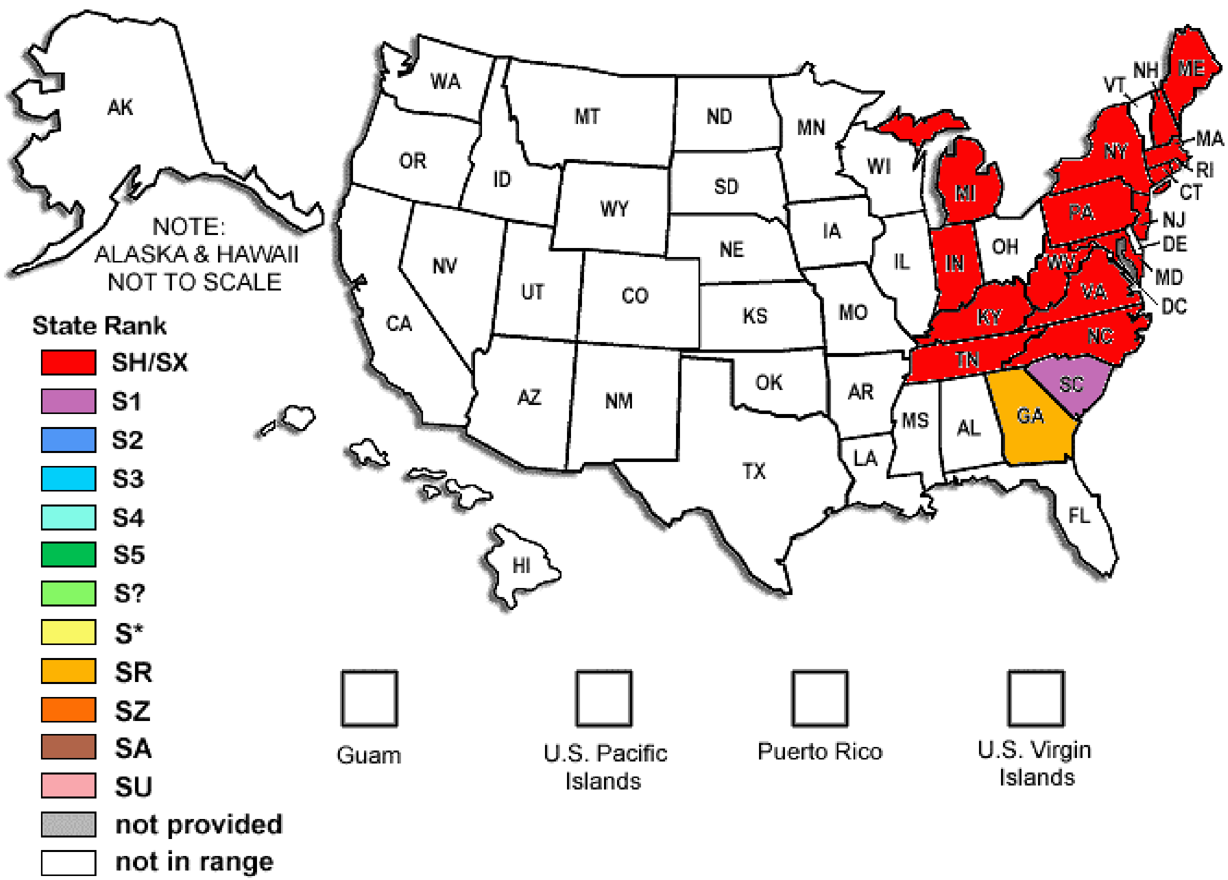


Rank Definition
SX- Extirpated
SH- Historical
S1- Critically Imperiled
SR- Reported

Figure 1. Historical Distribution of *Puma concolor cougar* (from TNC 2000)

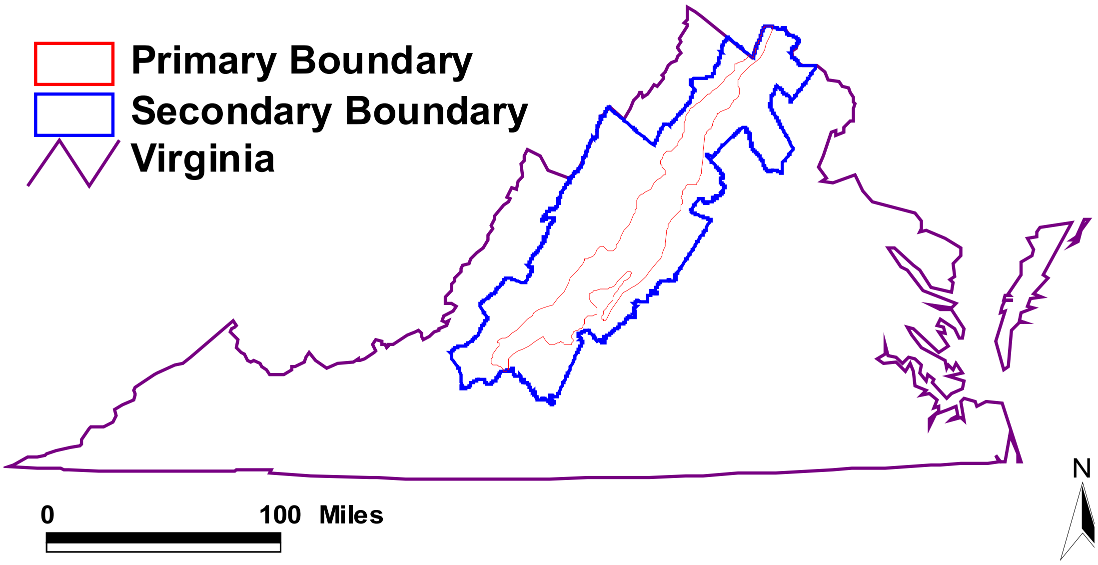


Figure 2. Northern Blue Ridge Study Areas

Table 1. Description of Spatial Data

Data Type	Source*	Original Format
Primary Area Boundary	USFS	Vector
Secondary Area Boundary	VA GAP	Shapefile
Sightings in Primary Area	SNP	Tabular
Sightings in Secondary Area	EPRN	Paper Map
Deer Harvest Density	VDGIF	Tabular
Elevation	USGS	Digital Elevation Model
Geology	USGS	Tabular, Shapefile
Human Population Density	ESRI	Tabular, Shapefile
Land Cover	VEDP	Landsat 7 TM Imagery
Landform	Generated from aspect, elevation, and slope.	
Road (Distance to Nearest)	VDOT	Vector
Stream/River (Distance to Nearest)	VA GAP	Vector

*EPRN (Eastern Puma Research Network), ESRI (Environmental Systems Research Institute), SNP (Shenandoah National Park), USFS (United States Forest Service), USGS (United States Geological Survey), VA GAP (Virginia Gap Analysis Project), VDGIF (Department of Game and Inland Fisheries), VDOT (Virginia Department of Transportation), VEDP (Virginia Economic Development Partnership).

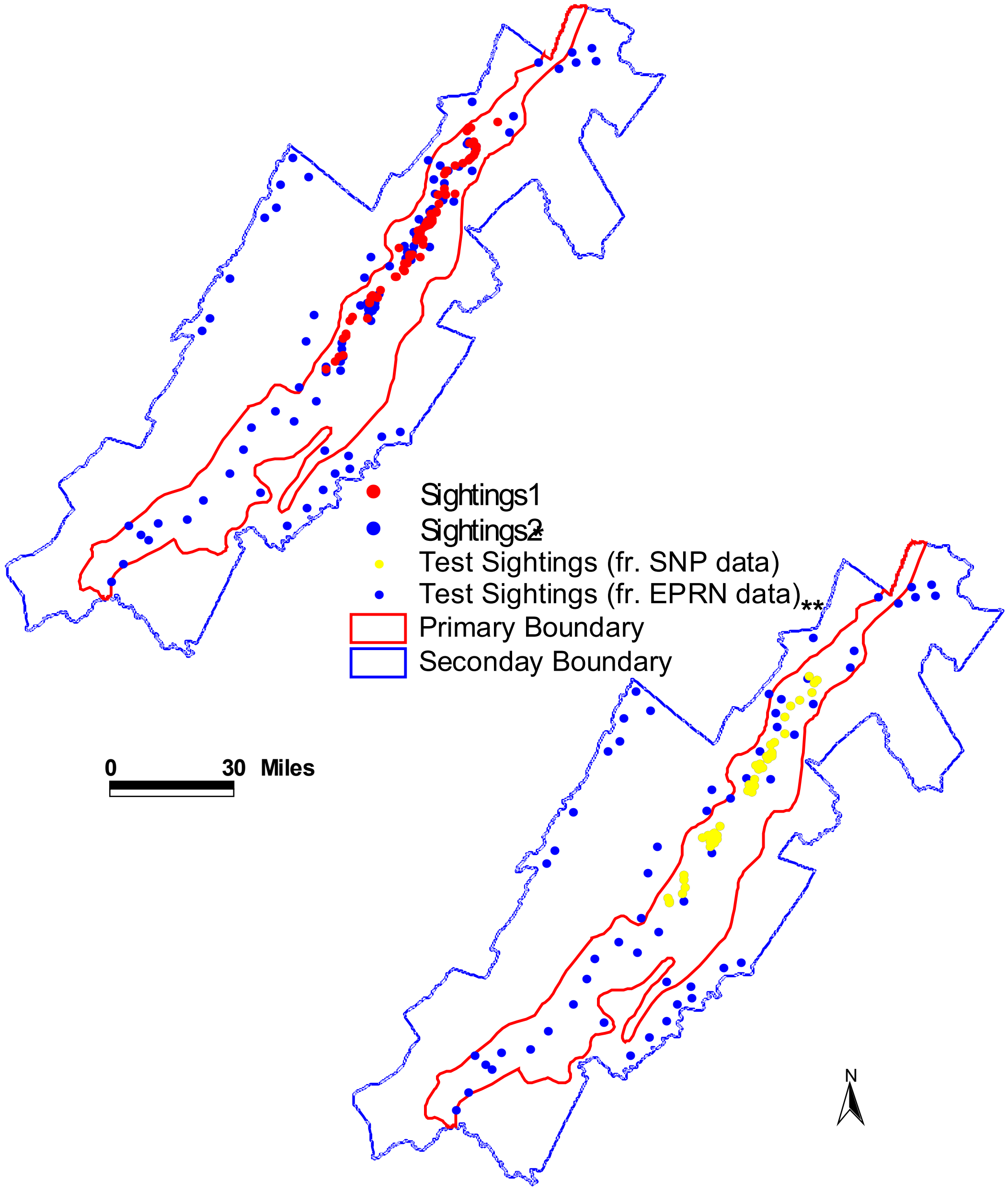


Figure 3. Eastern Cougar Sighting Locations
*Top figure
**Bottom figure

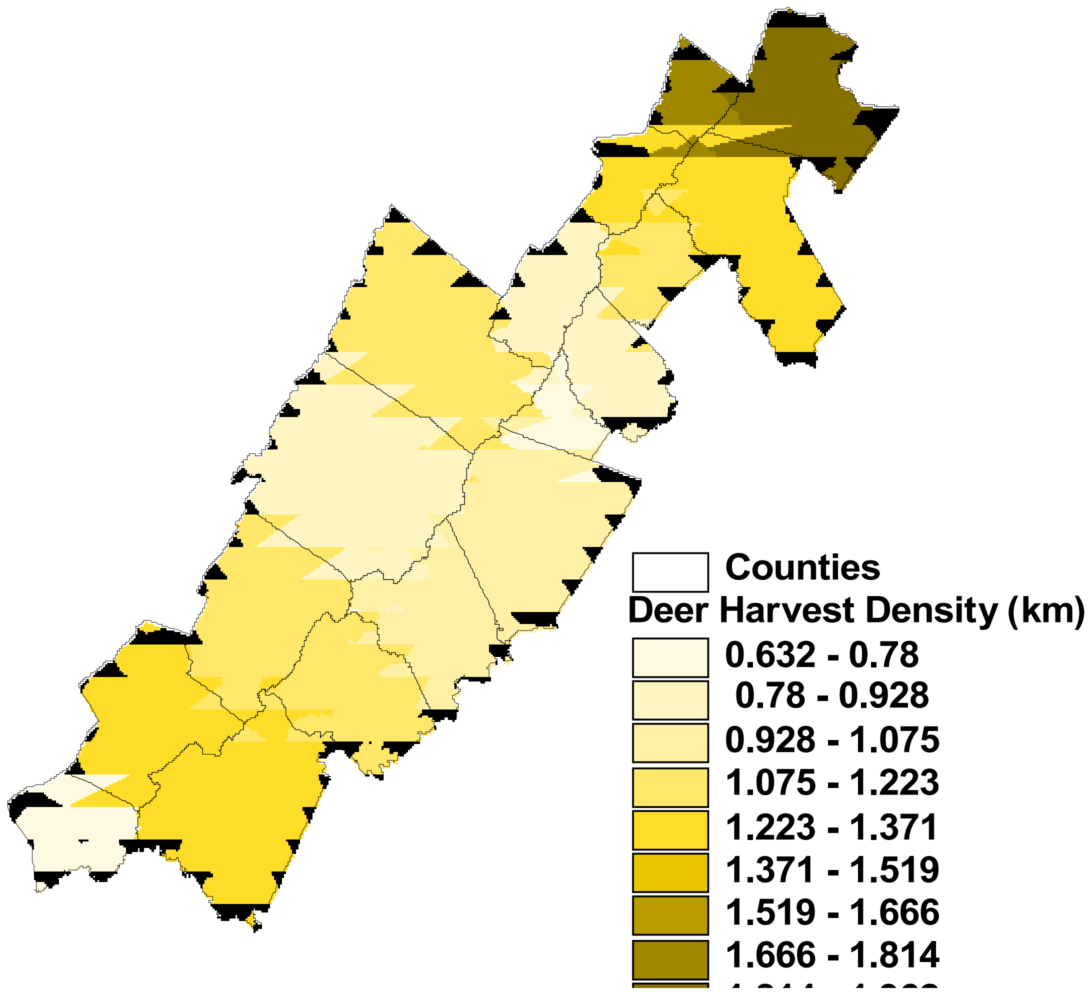


Figure 4. Deer Harvest Density

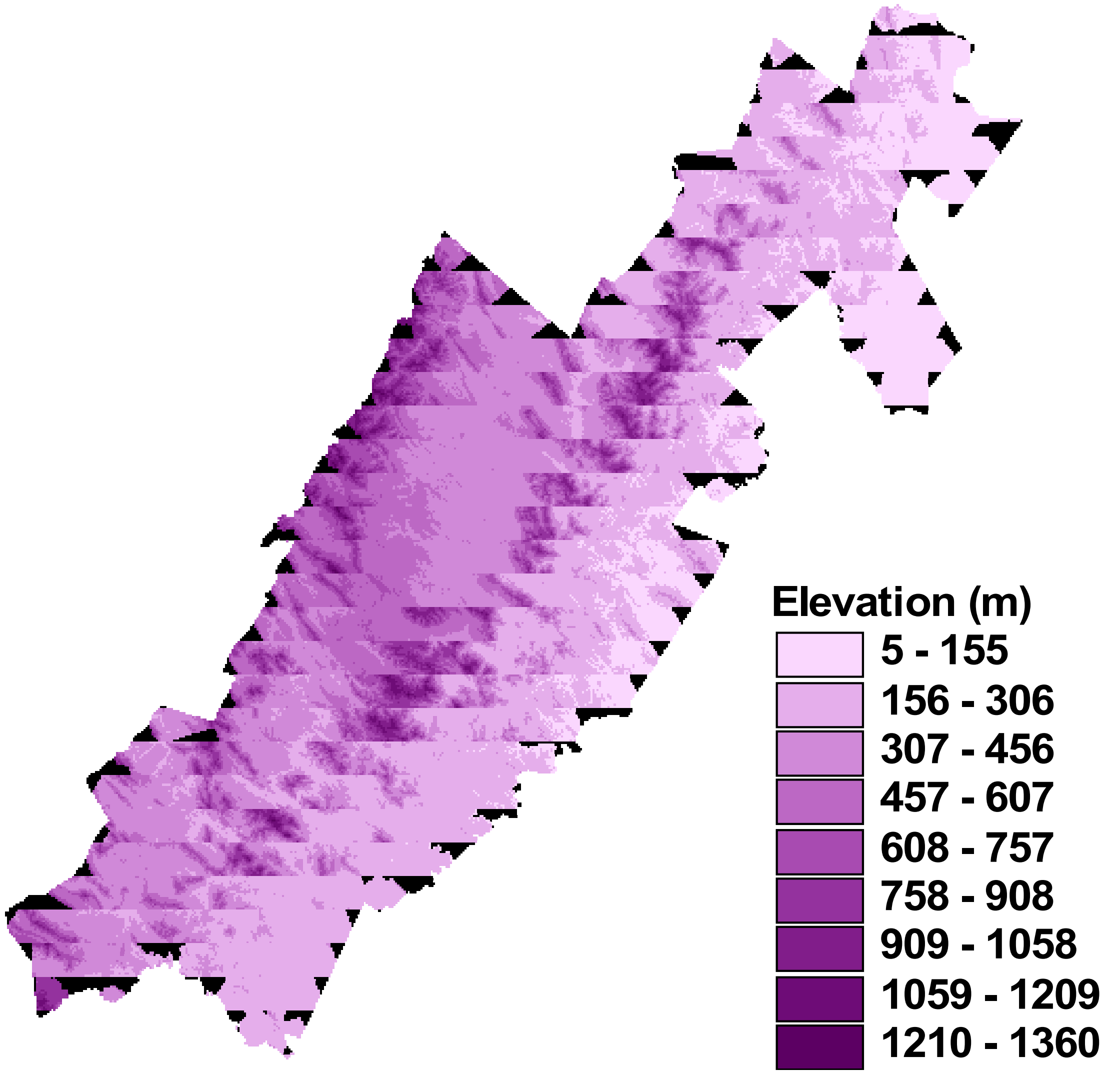


Figure 5. Elevation

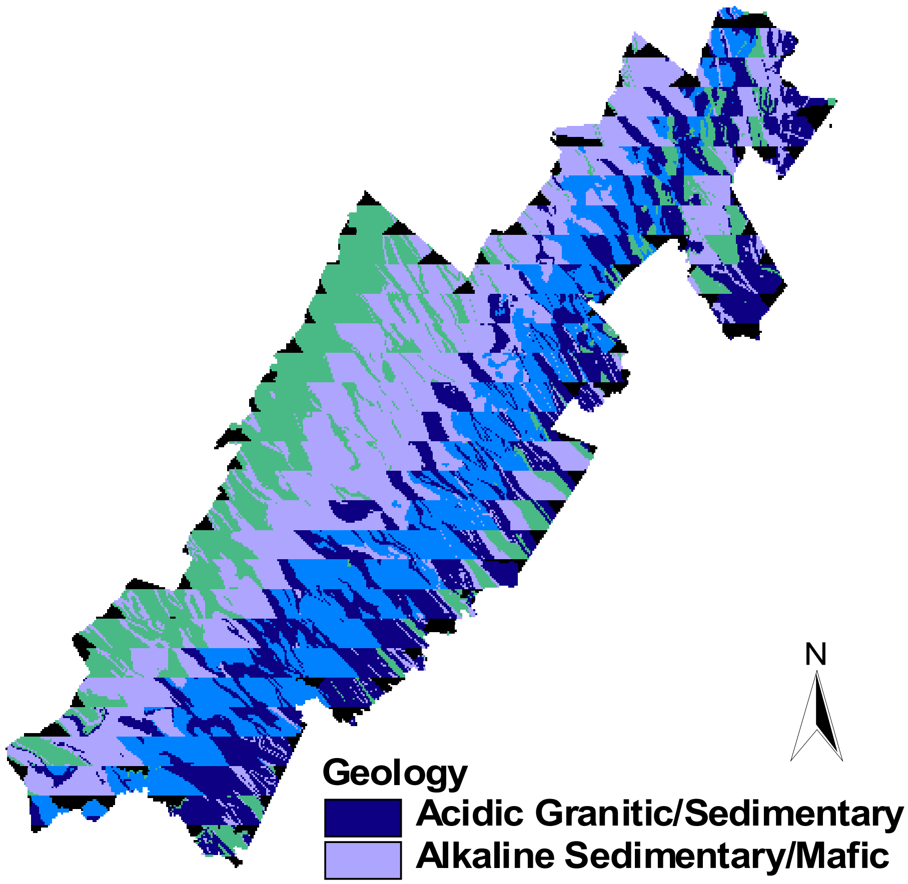


Figure 6. Geology

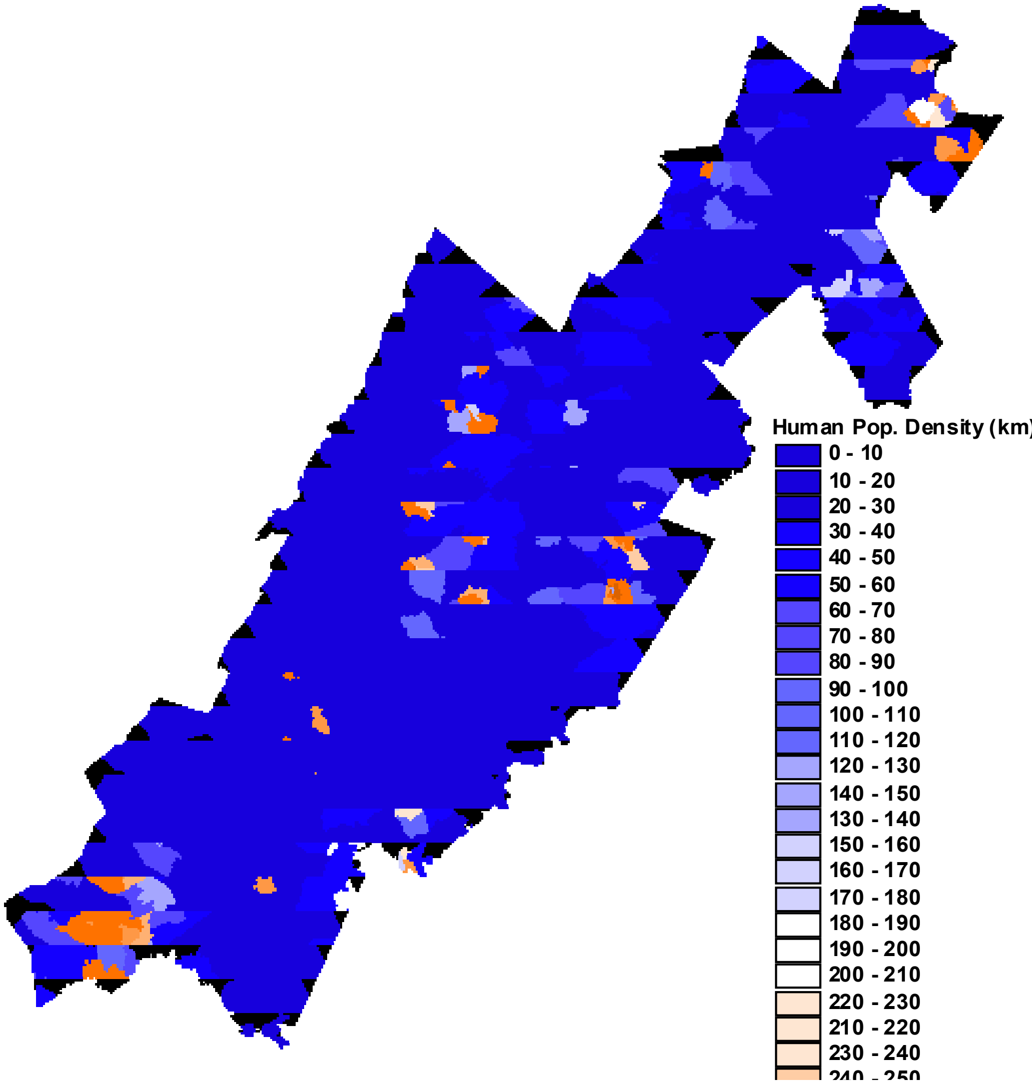


Figure 7. Human Population Density

Table 2. Land Cover Accuracy Assessment (Initial)

Class	Producers Accuracy	Users Accuracy
Non-forested	0.120	0.150
Rock Outcrop*	0.123	0.100
Forested	0.555	0.680

*Prior to DOQQ correction.

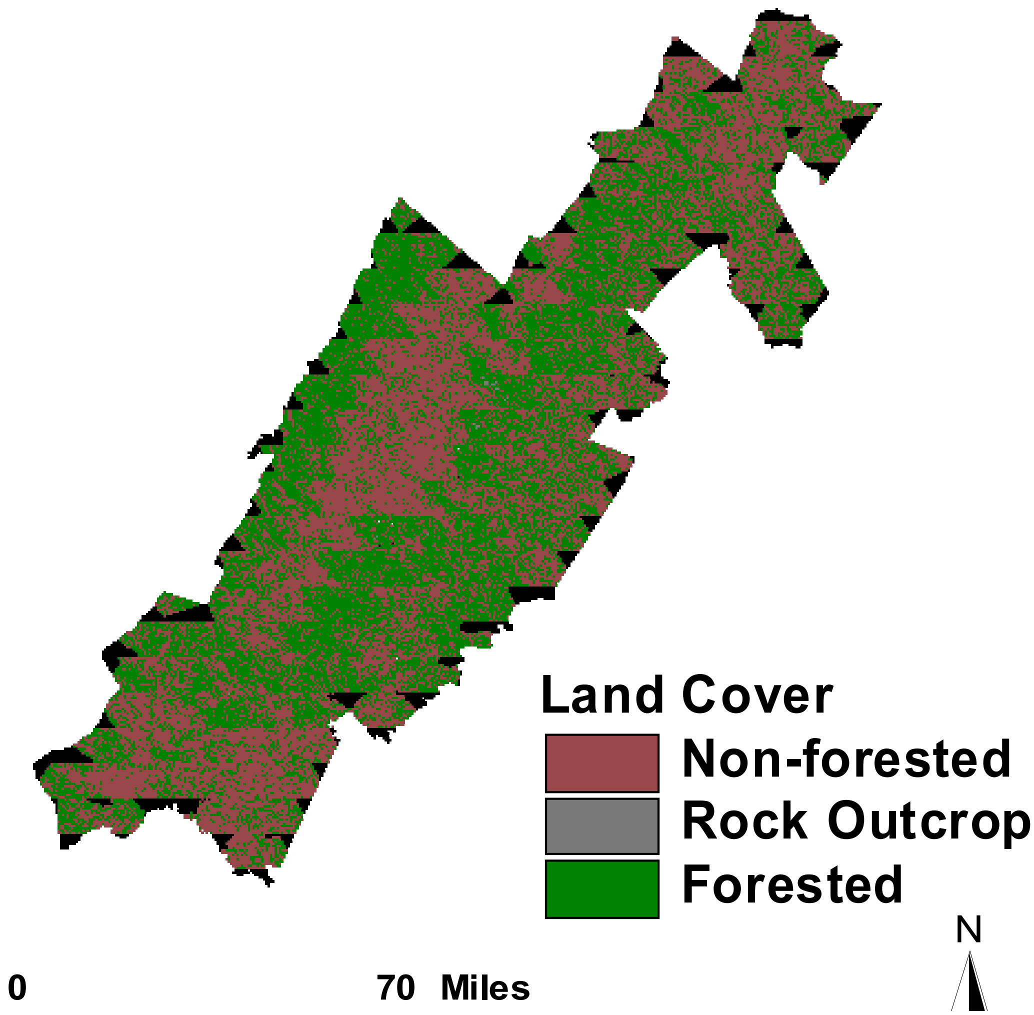
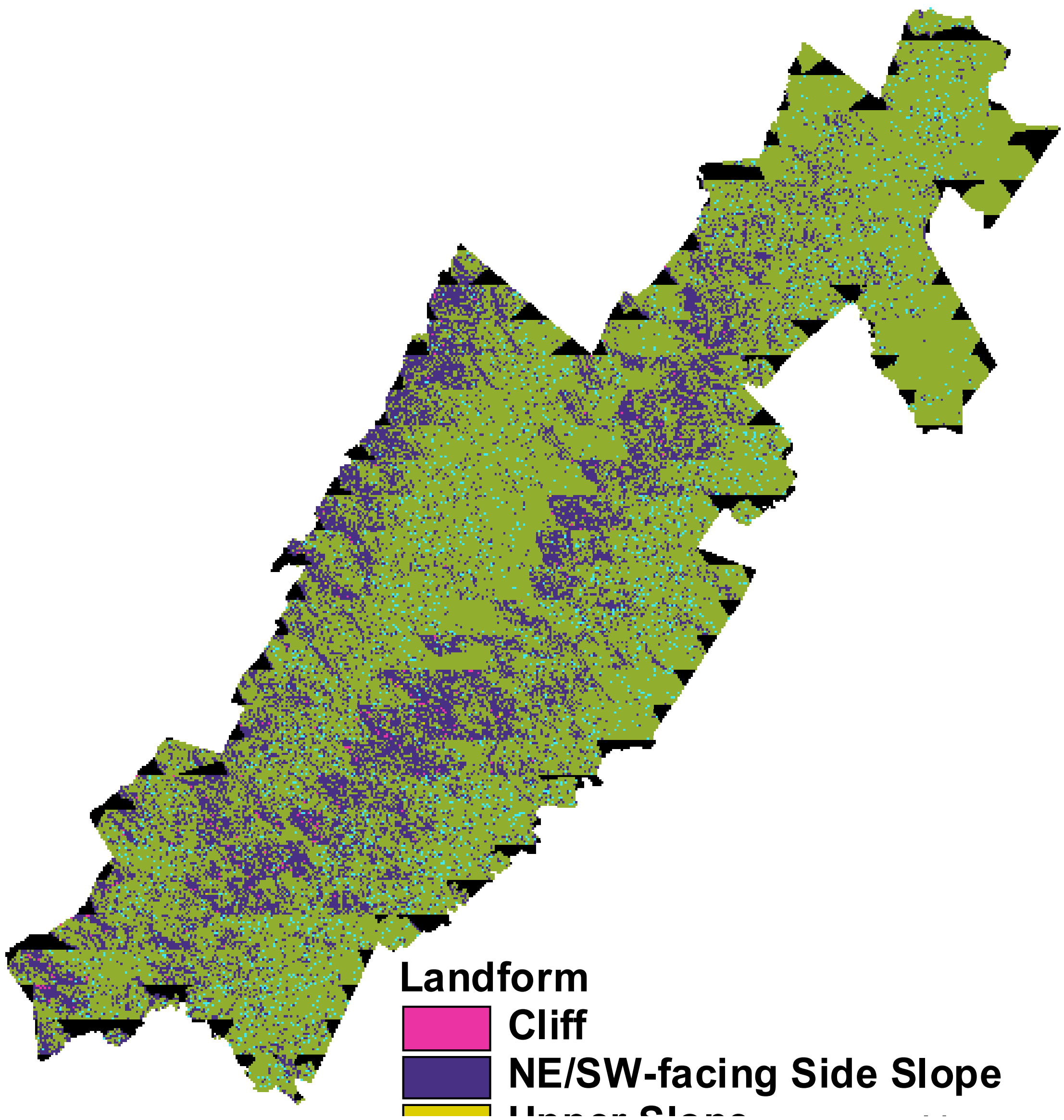


Figure 8. Final Land Cover



Low Slope/Cove

Figure 9. Landform Coverage

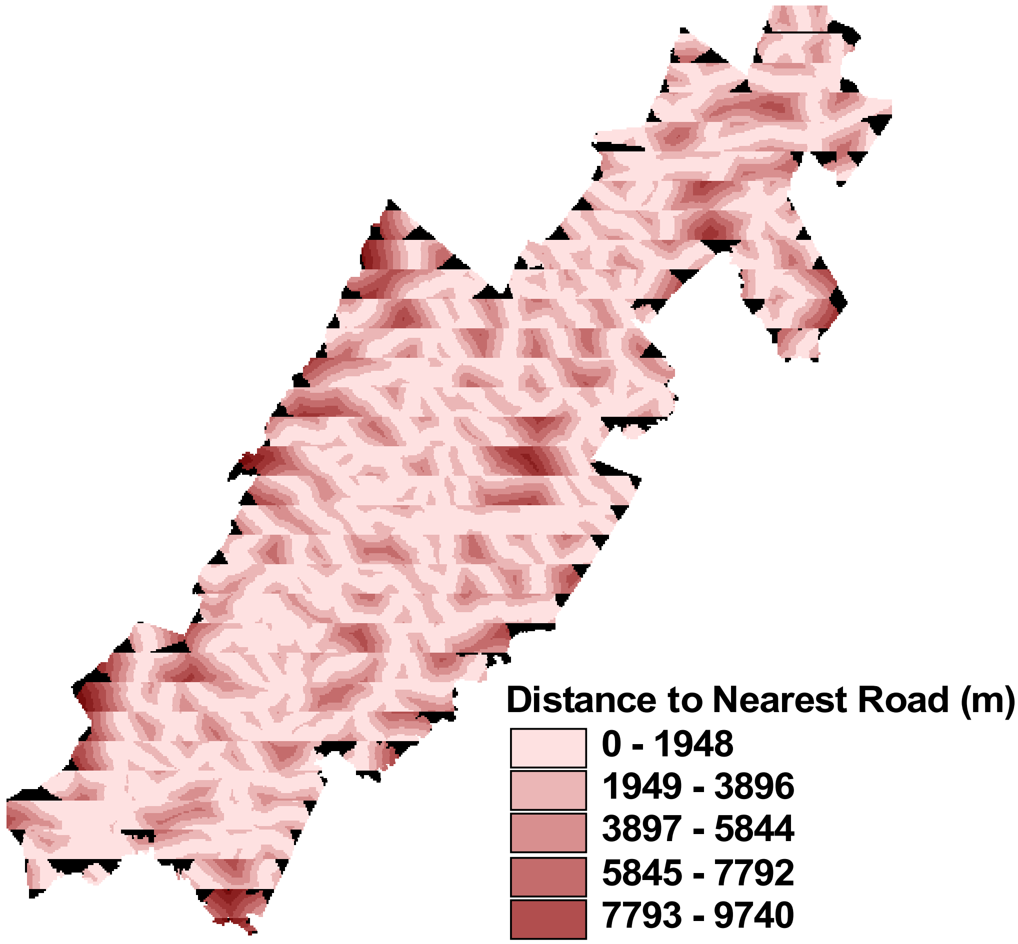


Figure 10. Distance to Nearest Road

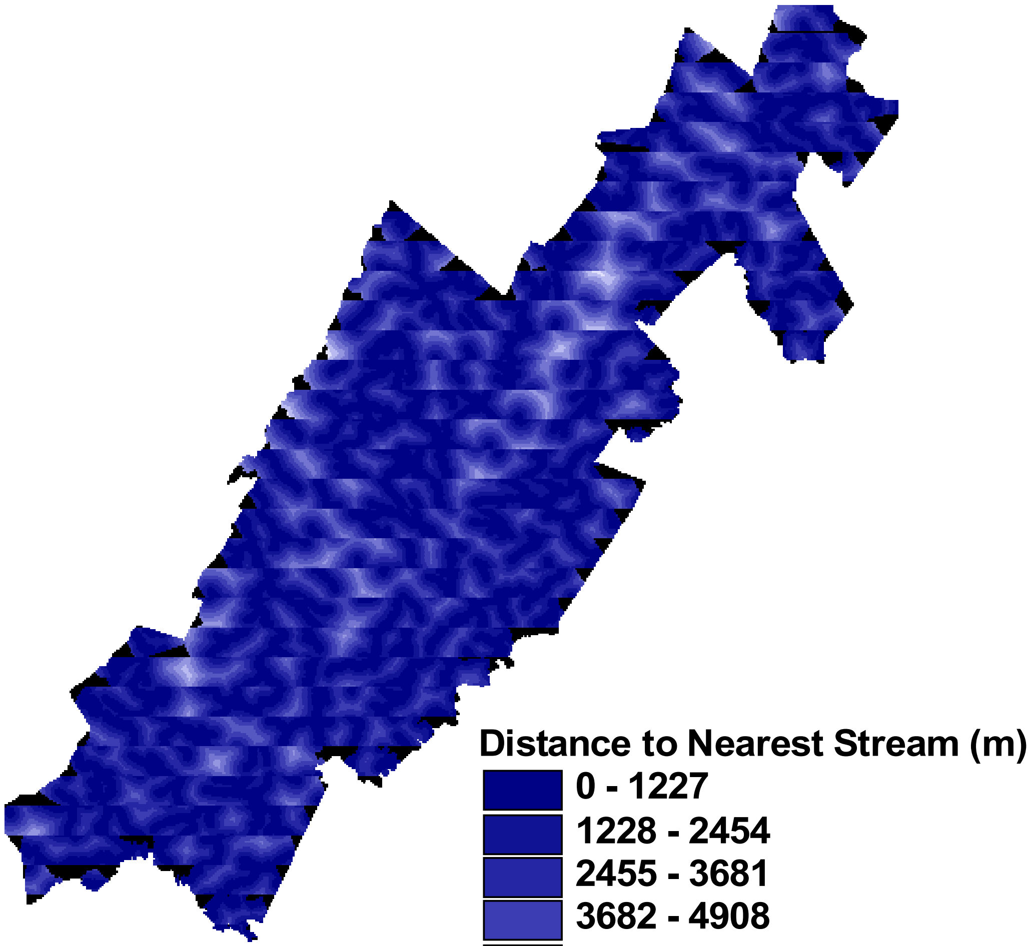


Figure 11. Distance to Nearest Stream/River

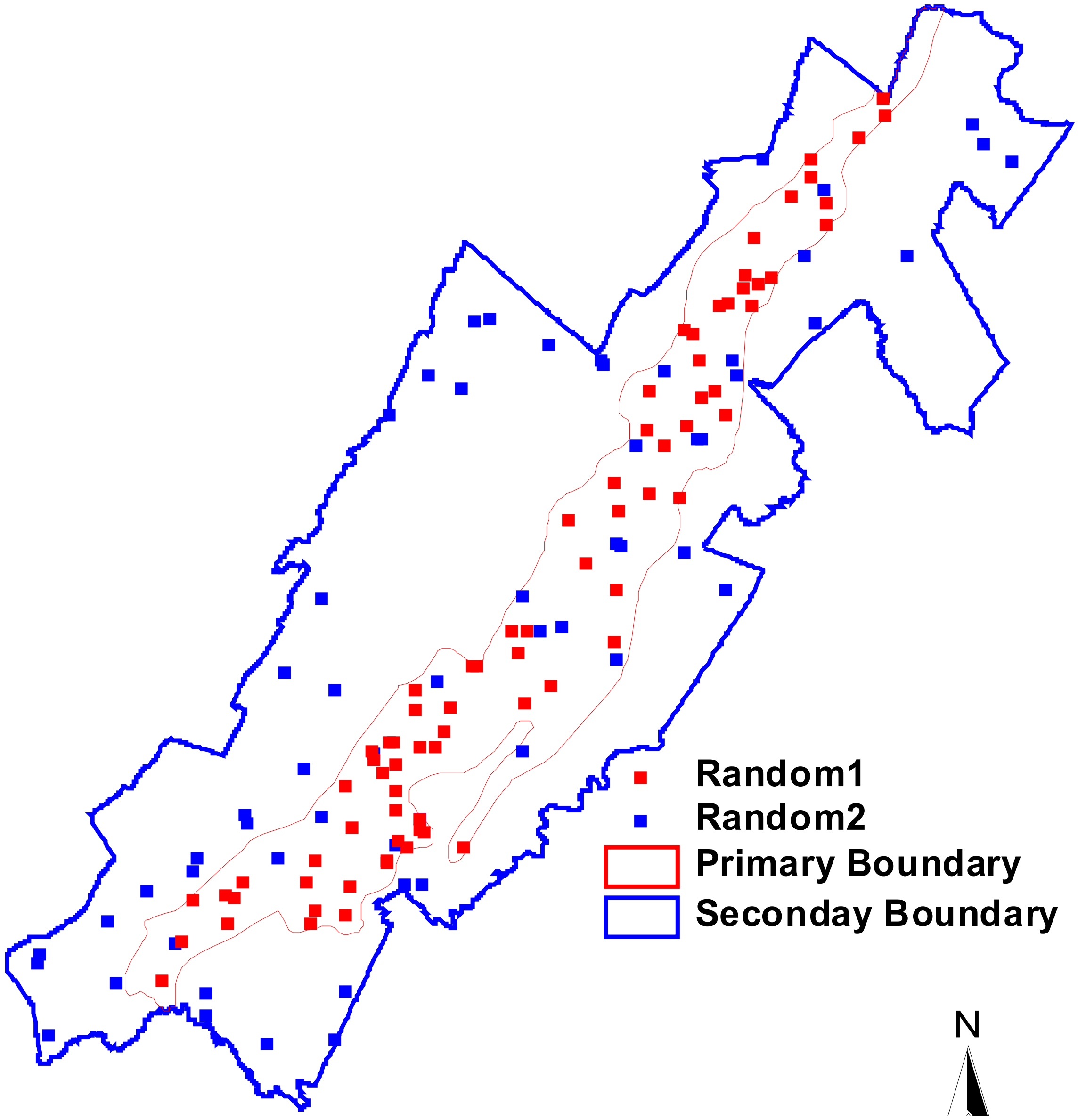


Figure 12. Random (Non-sighting) Locations

Table 3. Logistic Regression Results

Environmental Variable	**Chi-Square (Primary Area)**	**Chi-Square (Secondary Area)**
Deer Harvest Density	1.490	0.407
Elevation	64.827***	0.018
Geology	10.057**	2.514
Human Population Density	0.819	1.646
Land Cover	0.125	0.034
Landform	6.269*	1.201
Road (Distance to Nearest)	27.700***	1.073
Stream/River (Distance to Nearest)	2.653	0.038

* = $p < 0.05$; ** = $p < 0.01$; and *** = $p < 0.001$

Table 4. Significant Environmental Variables at Sighting Locations in Primary Area

Environmental Variable	**Modal Value/Class**	**Minimum/Maximum**
Deer Harvest Density	0.8 / km^2	0.6/km^2 / 1.3/km^2
Elevation	>850 m	283 m /1200 m
Geology	Acidic/Granitic Sedimentary	NA
Human Population Density	11.0 /km^2	9.5/km^2 / 71.4 km^2
Land Cover	Forested	NA
Landform	NE/SW-facing Side Slopes	NA
Road (Distance to Nearest)	≤ 0.2 km	15 m / 4730 m
Stream (Distance to Nearest)	≤ 5.6 km	1649 m / 9683 m

Table 5. Odds-ratio Estimates from Logistic Regression in Primary Area

Variable	Class (Categorical Variables)	Estimate
Elevation	NA	1.008
Geology	Acidic/Granitic Sedimentary vs. Alkaline Sedimentary/Mafic	2.475
Geology	Alkaline Sedimentary/Mafic vs. Basic Granitic	11.860
Landform	NE/SW-facing Sideslope vs. Flat	0.038

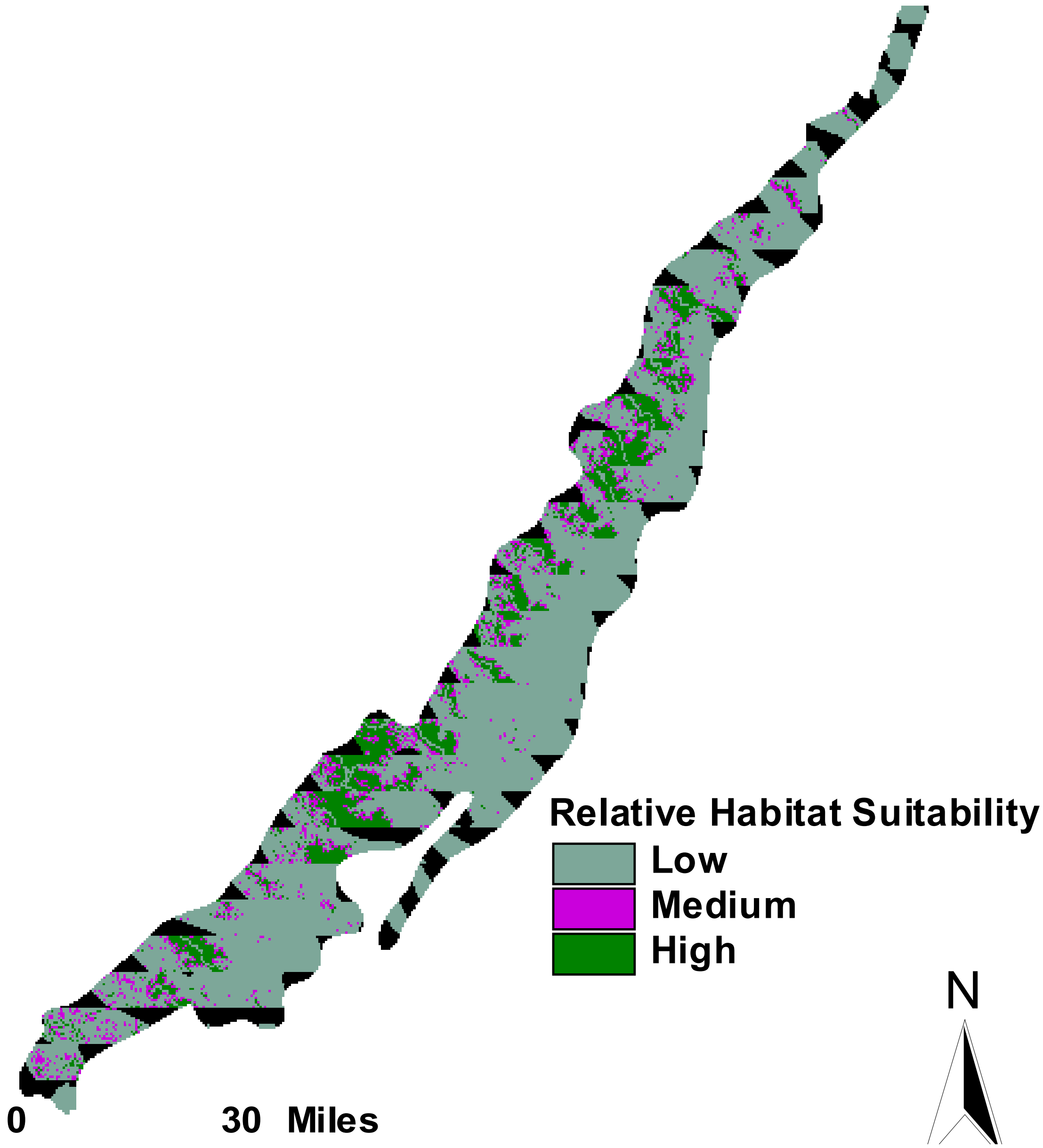


Figure 13. Relative Habitat Suitability for Primary Area

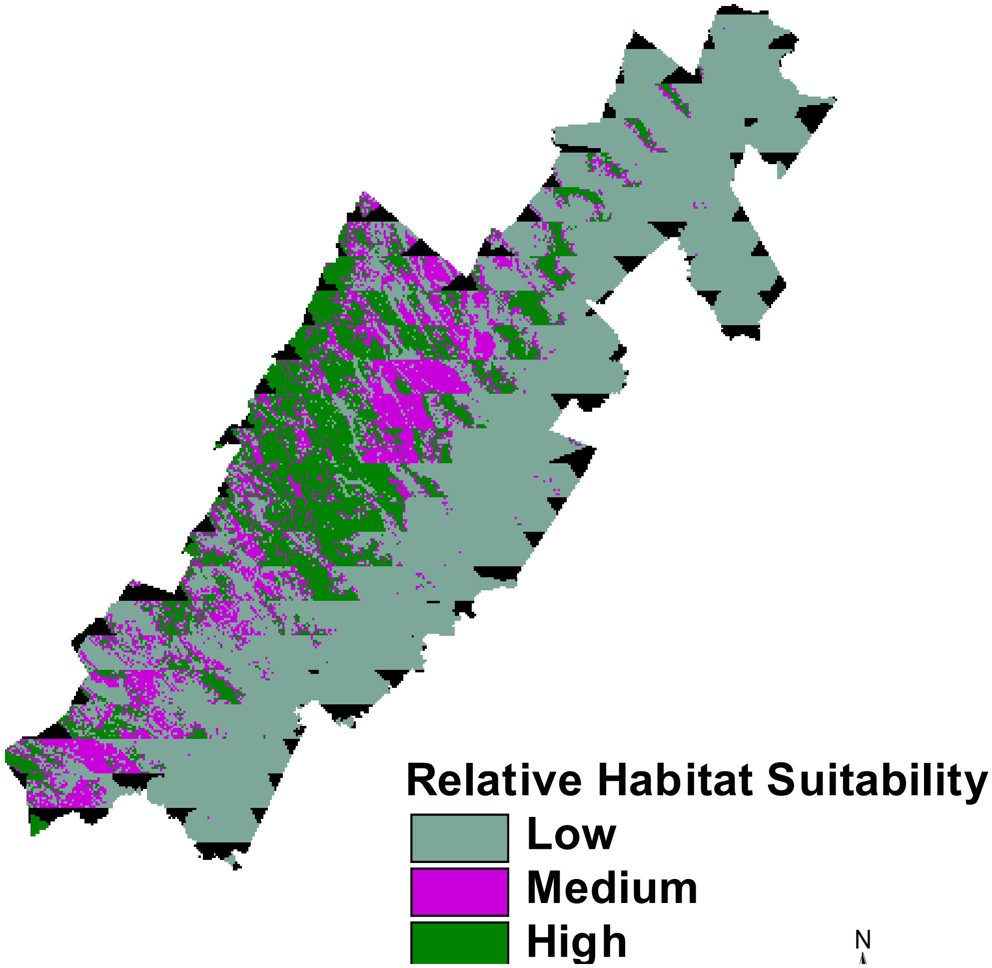


Figure 14. Relative Habitat Suitability for Secondary Area

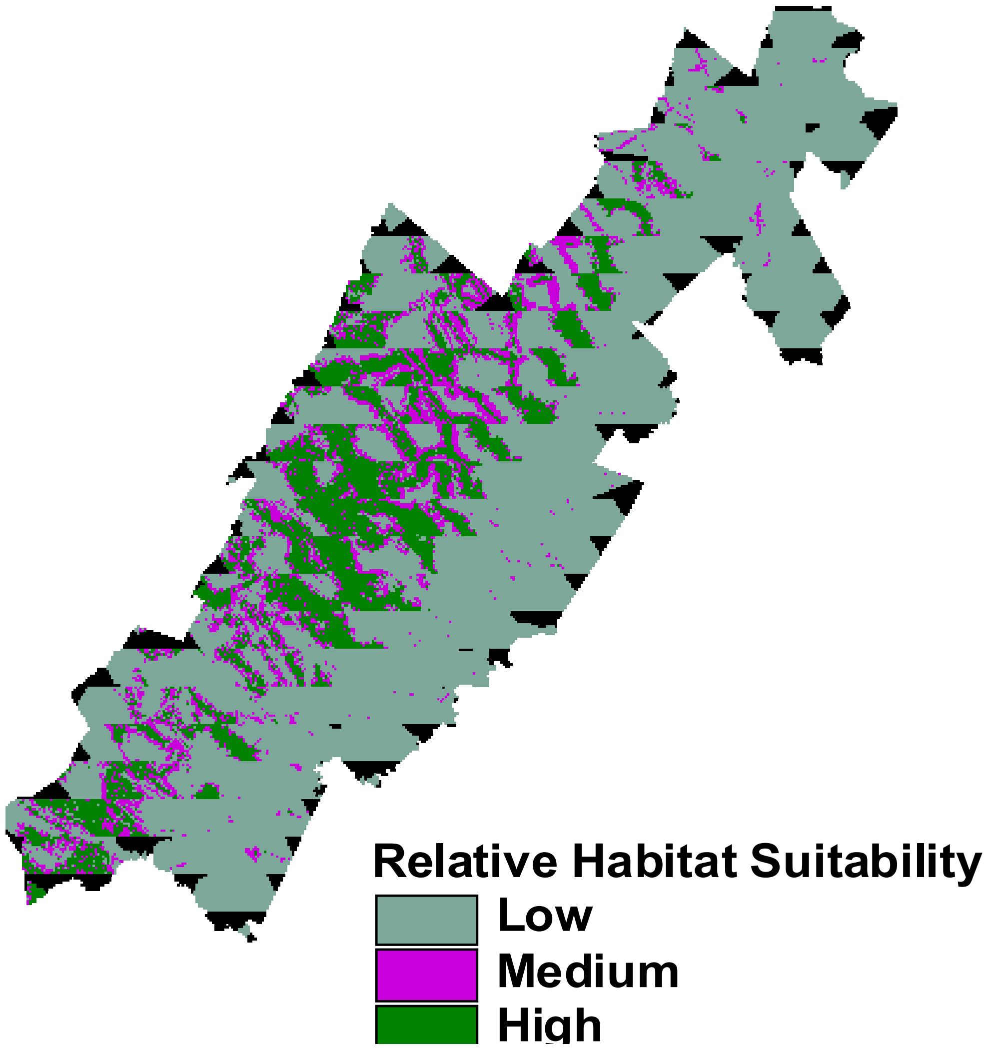


Figure 15. Relative Habitat Suitability Model with Roads Variable for Secondary Area

Table 6. Habitat Models and Relative Suitability Areas

Models	Relative Habitat Suitability					
	Area (km^2)			Relative Area		
	Low	**Medium**	**High**	**Low**	**Medium**	**High**
Primary Area	4798	505	809	78.5%	8.3%	13.2%
Secondary Area	14359	3213	4192	66.0%	14.8%	19.3%
Secondary Area*	15731	2366	3626	72.4%	10.9%	16.7%

*Regression equation included roads variable.

Table 7. Characteristics of Relatively High Suitable Habitat Areas

Environmental Variables	Primary Area Habitat*	Secondary Area Habitat*	Secondary Area Habitat* **
Deer Harvest Density	1.00/km^2 0.63-1.96/km2	0.96/km^2 0.63-1.96/km2	0.96/km^2 0.63-1.96/km2
Elevation	805 m 390-1282 m	650 m 406-1360 m	594 m 270-1360 m
Geology	Alkaline Sedimentary/Mafic	Alkaline Sedimentary/Mafic	Alkaline Sedimentary/Mafic
Human Population Density	21/km^2 7-889/km^2	34/km^2 6-2261/km^2	79/km^2 6–2261/km^2
Land Cover	Forested	Forested	Non-forested
Landform	NE/SW-facing Side Slope	Low Slope/Cove	Low Slope/Cove
Road (Distance to Nearest)	1956 m 201-8997 m	2989 m 0-17532 m	1072 m 0-9900 m
Stream/River (Distance to Nearest)	4869 m 14-10198 m	3580 m 0-11045 m	3173 m 0-11045 m

*Averages and ranges provided for continuous variables; mode values provided for categorical variables.
**Regression equation included roads variable.

Table 8. Chi-square Analysis of Habitat Model Tests

Models	P-value	Test Statistic	Test Sightings in Low Suitability	Test Sightings in Medium/ High Suitability
Primary Area[1]	0.025	5.000	33%	67%
Secondary Area[1]	0.004	8.397	59%	41%
Secondary Area[2]	<0.001	32.8372	65%	35%
Secondary Area*[1]	<0.001	28.5522	98%	<2%
Secondary Area*[2]	<0.001	17.917	49%	51%

*Regression equation included roads variable.
[1]Tested with SNP sighting data
[2]Tested with SNP and EPRN sighting data